

Coal/Shale-Seq III
Advancing the Science of CO_2 Sequestration in Coal Seams and Gas Shale Reservoirs

Presented to:

DOE/EPA

Pittsburgh, PA

Presented by:

Advanced Resources International, Inc

George J. Koperna, Jr., Principle Investigator

March 23-24, 2010

Southern Illinois University

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Laboratory Goals

- **Understand the changes in coal and shale mechanical strength properties and thus permeability in the presence of high pressure CO_2.**
- **Understand the changes in cleat and matrix swelling and shrinkage and thus permeability due to injection of CO_2 under field replicated conditions.**
- **Understand the CO_2 and other gas adsorption behavior in wet coals and shales, with water as a separate adsorption component.**

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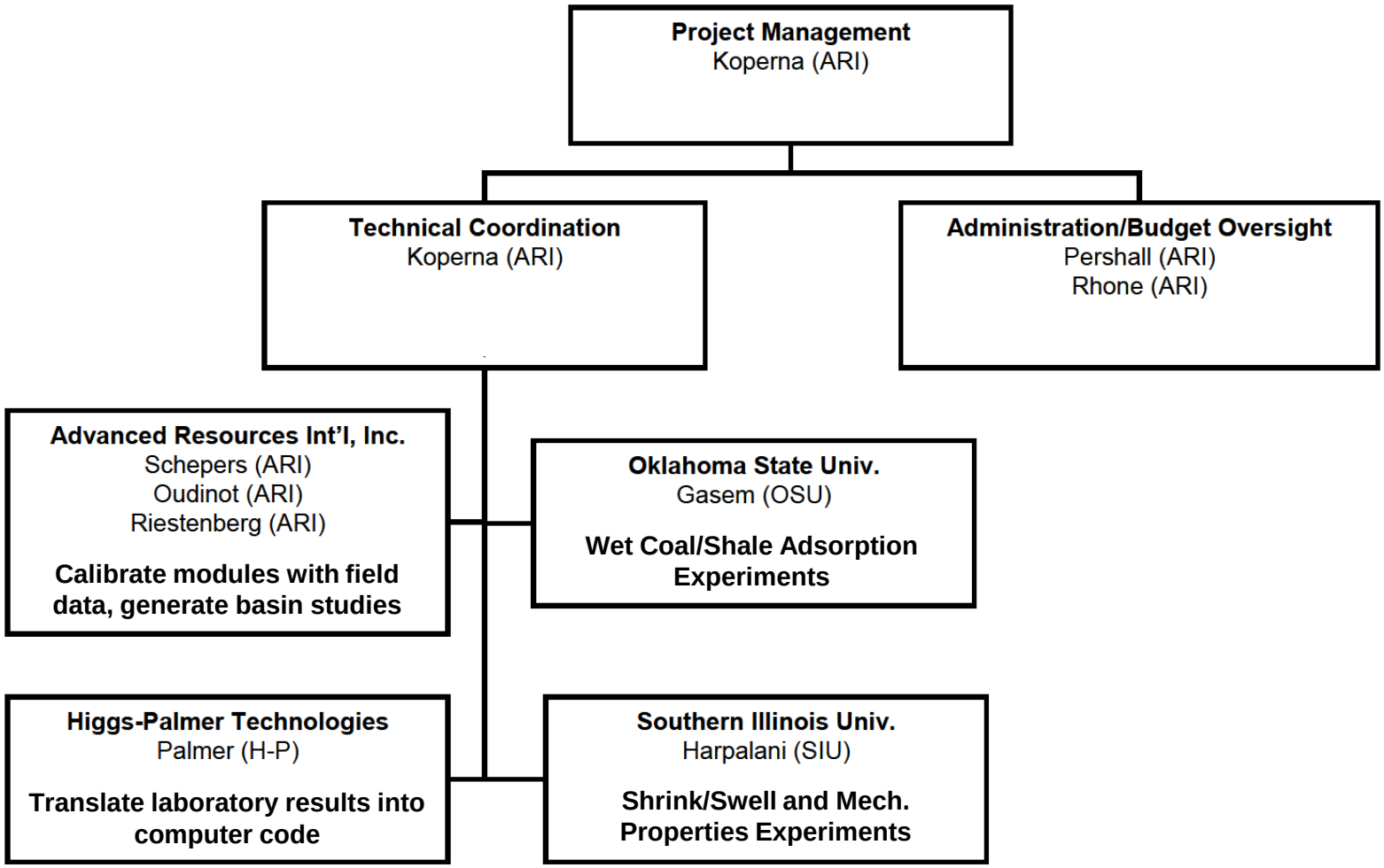
Project Goals

- Transfer laboratory understanding to computer code
- Rigorously test computer code against large scale CO_2 sequestration pilots
- Independently evaluate coal weakening and permeability changes in the presence of CO_2
- Evaluate the feasibility of large scale CO_2 storage in shale and coal reservoir
- Complete EOS Experiments
- Technology Transfer

Organizational Chart for Coal/Shale-Seq III Technical and Administrative Management



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Project Team and Facilities

- **Dr. Satya Harpalani, Ph.D., Professor and Chair, Department of Mining and Mineral Resources Engineering, Southern Illinois University**
  - SIU has high pressure CO_2 and other gas core flooding equipment as well as the key ultrasonic velocity instrumentation for nondestructive testing of coal and shale.
- **Dr. Khaled Gasem, Ph.D., Bartlett Chair and Head, School of Chemical Engineering, Oklahoma State University**
  - Oklahoma State University has comprehensive, high-pressure coal and shale experimental facilities which have been recently enhanced by the addition of two Advanced Technology Research Centers.

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Project Team and Facilities

- **Dr. Ian Palmer, Ph.D., Higgs-Palmer Technologies**
  - Mr. Palmer will oversee the translation of the scientific concepts into computer code and the coupling of the effects of physical and chemical processes within an advanced simulation model.
- **Mr. George Koperna, M.S., Vice-President, Advanced Resources International, Inc.**
  - ARI's facility in Arlington, VA, has a full suite of project management software and computers as well as ARI's *COMET3* simulation software that will serve as the platform for calibrating the coupled CO_2 sequestration modules.

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Consortium Members

BG GROUP

bp

ICCI
Illinois Clean Coal Institute
Energy Research for a Cleaner Environment

sasol
reaching new frontiers

NYSERDA

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Project Budget

	BP 1 (Oct 09-Dec 10)		BP 2 (Jan 11-Mar 12)	
	DOE	Non-DOE	DOE	Non-DOE
ARI (Prime*)	$181,465	$181,465	$292,317	$292,317
OSU	$171,981	$250,289	$111,033	$171,741
SIU	$155,270	$155,270	$87,935	$87,935
Total:	$508,716	$587,024	$491,284	$551,992
CS %:		54%		53%

***The budget for the Prime Applicant, ARI, includes the Higgs-Palmer sub-awardee with a total budget below $100,000.**

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Task Overview

Task 1: Project Management, Planning and Reporting

Task 2: Changes in Coal and Shale Properties with Exposure to CO_2

Task 3: Cleat and Matrix Swelling/Shrinkage Compressibility under Field Replicated Conditions (including Shale)

Task 4: Modeling of CO_2 Injection under In-Situ Conditions

- Adsorption in the presence of water
- Mixed gas EOS development

Task 5: Advanced Modeling of Permeability Changes during CO_2 Sequestration

Task 6: Technical Transfer

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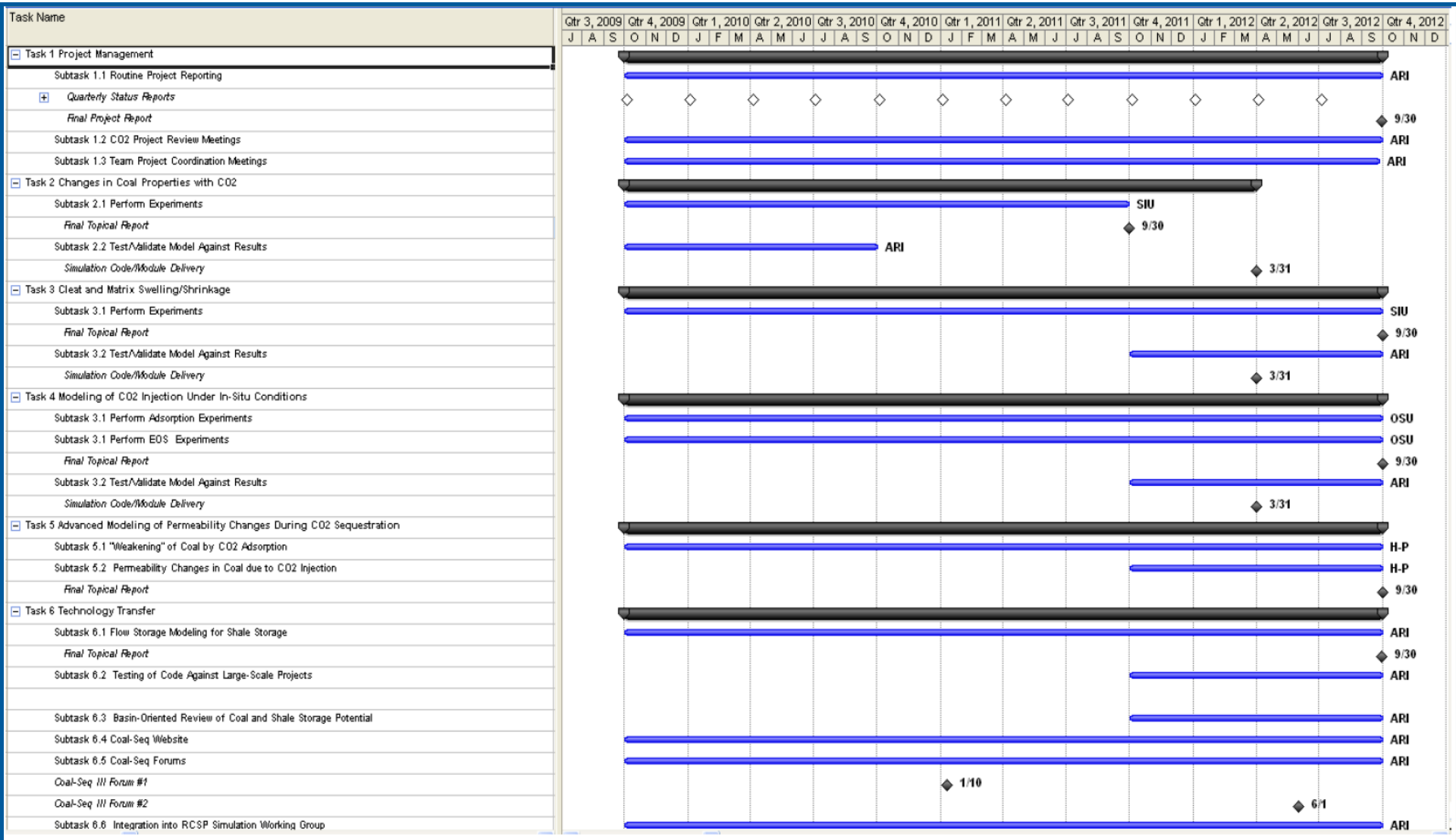
Project Timeline/Gantt Chart



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Coal/Shale-Seq III Project Milestone Log

BP	Milestone Description	Comp Date	Verification
1	Complete laboratory setup and begin experiments (Tasks 2-4)	Mar 31, 2010	
1	Collect NYSERDA shale dataset	June 30, 2010	
2	Changes in coal properties with exposure to CO_2	Sept 30, 2011	Final topical report
2	Changes in coal properties with exposure to CO_2	Sept 30, 2011	Sim model/code delivered to DOE
2	Cleat and matrix swelling and shrinkage compressibility under field replicated conditions	Mar 31, 2012	Sim model/code delivered to DOE
2	Cleat and matrix swelling and shrinkage compressibility under field replicated conditions	Sept 30, 2012	Final topical report
2	Modeling of CO_2 injection under in situ conditions	Mar 31, 2012	Sim model/code delivered to DOE
2	Modeling of CO_2 injection under in situ conditions	Sept 30, 2012	Final topical report
2	Advanced modeling of permeability changes during CO_2 sequestration	Sept 30, 2012	Final topical report
2	Flow and storage modeling for shale sequestration	Sept 30, 2011	Final topical report
2	Code validation using large-scale sequestration data sets	June 30, 2012	Final topical report
2	Basin-oriented review of coal/shale storage pot. – Marcellus and Utica shales of the App Basin	Mar 31, 2012	Final topical report
2	Basin-oriented review of coal/shale storage pot. – Fruitland Coal of the San Juan Basin	Sept 30, 2012	Final topical report
1	Coal/Shale Seq III – Forum 1	Jan 2011	
2	Coal/Shale Seq III – Forum 2	June 2012	

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Where We Are Today

- All subcontracts are in place with researchers
- Laboratory setup is underway
- Internal project meeting planned (April 9th in Houston)
  - Discuss sampling selection and testing strategies
- Additional consortium participants being sought

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Southern Illinois University Research Objectives

- Does the coal “weaken” as a result of continued CO_2 injection? Specifically, does injectivity improve/decline as methane is depleted and CO_2 saturation increases?

- Modeling support: How do cleat and matrix swelling/shrinkage compressibilities vary with continued CO_2 injection?

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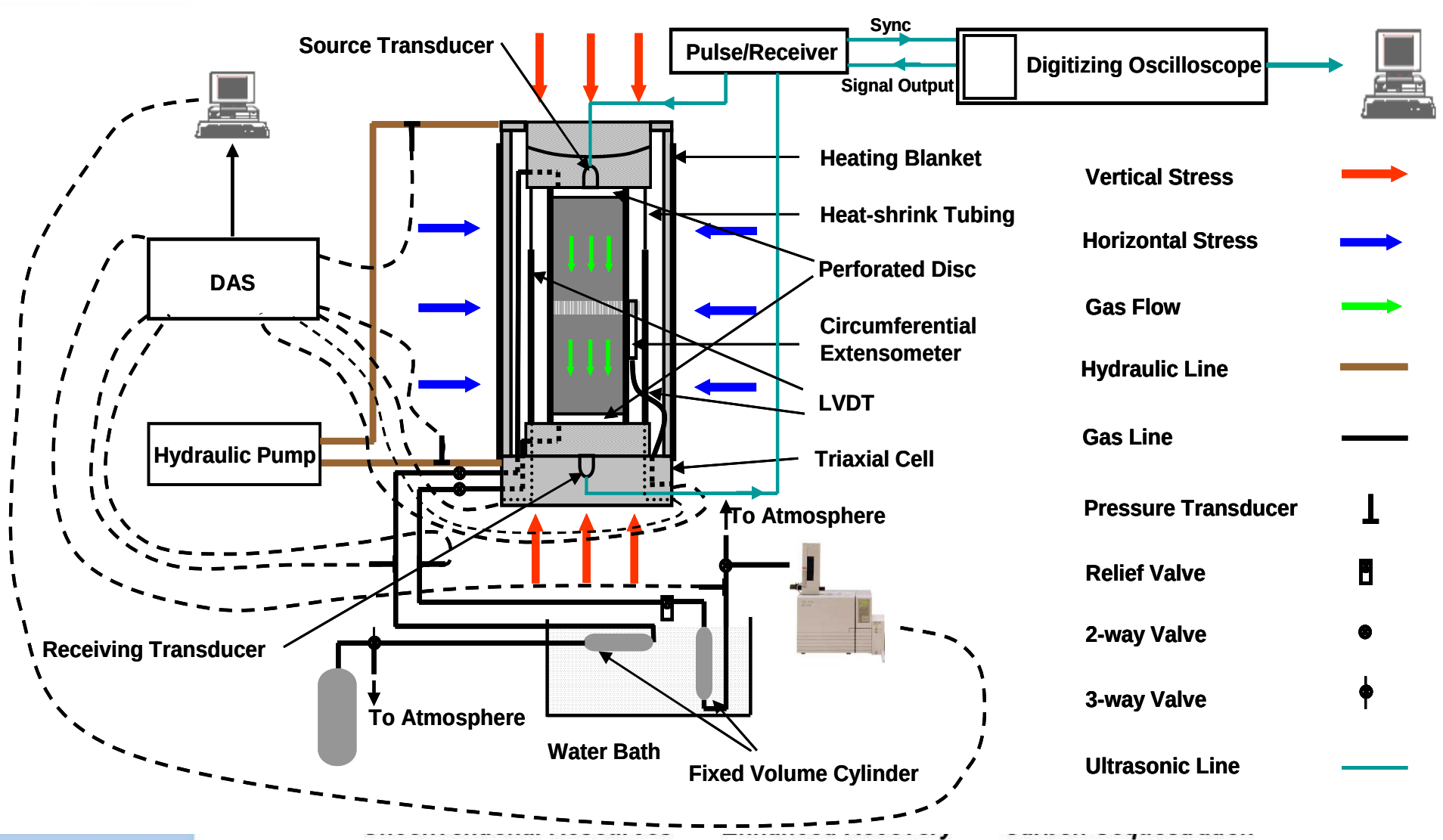
Southern Illinois University Setup Capabilities

- Control of vertical and horizontal ***stresses*** ***(in situ mechanical conditions)***
- ***Temperature*** control ***(in situ conditions)***
- Measurement of vertical and horizontal ***strains (deformation)*** – shrinkage/swelling characteristics ***(for modeling)***
- Control of upstream and downstream ***gas pressures*** – provide pressure gradient for ***flow conditions***
- Measurement of ***flow rate*** – permeability (***modeling***)
- Measurement of ***sonic velocity*** – modulus (E, ν) (***strength)***
- Measurement of ***gas composition*** ***(flow conditions)***

Southern Illinois University Experimental Setup



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Oklahoma State University Experimental Work

- The OSU Adsorption Lab used for isotherm measurements is being re-commissioned.
- A complete density measuring apparatus (DMA) has been ordered. This apparatus will facilitate precise and accurate gas density measurements.
- The DMA apparatus uses the vibrating U-tube principle, which is widely regarded as the most accurate method for measuring fluid densities.
- Experimental design is being optimized to minimize the expected uncertainties in the gas density measurements.

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Oklahoma State University Algorithm Development

- Rigorous phase equilibrium calculations required in CO_2 sequestration are relatively complex because as many as three phases (adsorbed, gas, and aqueous) may co-exist.
- Computational methods for multiphase equilibrium behavior were reviewed.
- A methodology combining Gibbs energy minimization and fugacity matching is being developed for multiphase high-pressure adsorption equilibria involving CBM gases and water.

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Oklahoma State University Future Work

- Experimental Work
  - Install DMA apparatus in the adsorption laboratory
  - Conduct gas density and adsorption isotherm measurements on wet coals
- Algorithm Development
  - Conduct multiphase analysis for CO_2-Water systems using the newly devised algorithm
  - Assemble a VLE and PVT database for the wet CBM systems
  - Evaluate current VLE and PVT equation-of-state predictions of systems involving CBM gases and water

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Hypothetical Sample Selection

Focus on diversity in both shales and coals. Final list TBD during April meeting

- Illinois Basin coal sample (3)
- San Juan Fairway coal sample
- Warrior Basin/Central Appalachian Basin coal sample
- Powder River Basin coal sample
- Mid-Continent coal sample (2)
- Marcellus/Utica shale sample
- Mid-Continent shale sample

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Summary

Coal/Shale-Seq III Plans to develop and test 3 advanced geochemical and geomechanical modules that would appreciably increase the accuracy of simulating the behavior of geologically sequestered CO_2 in coals and shales. These are:

- Impact of high pressure CO_2 on the mechanical strength of coal and shale
- Coal and shale shrinkage/swelling under field replicated conditions
- Determination of the role of water as a separate adsorption component in coal/shale reservoirs

A special feature of Coal/Shale-Seq III will be the development of improved simulation capability for injecting and storing CO_2 in gas shales, enabling investigators to better evaluate this large, poorly understood CO_2 storage option, particularly in the Appalachian Basin

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EXTRAS

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Task 1:

ARI Responsibilities:

- Project oversight
- Integration of reporting and budget information
- Communication with DOE and NETL
- Conduct technical reviews
- Manage and Monitor budget and work performance

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Task 1: (cont'd)

Subtask 1.1: Routine Project Reporting

Subtask 1.2: COR Project Review Meetings

Subtask 1.3: Link to DOE Working Groups

Subtask 1.4: Annual Meetings and Forums

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Task 2: Changes in Coal Properties with Exposure to CO_2

Subtask 2.1: Perform Experiments

Subtask 2.2: Test/Validate Module against Results

Deliverable: Simulation Code/Module (September 30, 2011)

Task 3: Cleat and Matrix Swelling/Shrinkage Compressibility under Field Replicated Conditions

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Subtask 3.1: Perform Experiments

Subtask 3.2: Test/Validate Module against Results

Deliverable: Simulation Code/Module (March 31, 2012)

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Task 4: Modeling of CO_2 Injection under In-Situ Conditions

The goal of this research Task is to develop improved algorithms and reliable coal structure- based generalized adsorption models to facilitate realistic simulation of CO_2 sequestration in coal seams and shale gas reservoirs. All the experimental measurements to be undertaken in this project are designed primarily to support our modeling and algorithm development efforts, which constitute essential components of a reliable simulation capability fully accounting for the phase behavior of CO_2 sequestration systems.

Subtask 4.1: Perform Adsorption Experiments

Subtask 4.2: Perform EOS Experiments

Subtask 4.3: Test/Validate Module against Results

Deliverable: Simulation Code/Module (March 31, 2012)

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Task 5: Advanced Modeling of Permeability Changes during CO_2 Sequestration

Subtask 5.1: "Weakening" of Coal by CO_2 Adsorption

Subtask 5.2: Permeability Changes in Coal due to CO_2 Injection

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Task 6: Technical Transfer

Subtask 6.1: Flow and Storage Modeling for Shale Sequestration

Subtask 6.2: Testing of Code against Large-Scale Projects

Subtask 6.3: Basin-Oriented Review of Coal and Shale Storage Potential

Subtask 6.4: Coal-Seq Website

Subtask 6.5: Coal-Seq Forums

Deliverables: Coal-Seq III – Forum 1 (January 2011) Coal-Seq III – Forum 2 (June 2012)

Subtask 6.6: Integration into RCSP Simulation Working Group

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Schedule - Deliverables

1. Changes in coal properties with exposure to CO_2 (Final Topical Report, September 30, 2011).
2. Changes in coal properties with exposure to CO_2 (Simulation Code/Module – September 30, 2011).
3. Cleat and matrix swelling/shrinkage compressibility under field replicated conditions (Simulation Code/Module - March 31, 2012).
4. Cleat and matrix swelling/shrinkage compressibility under field replicated conditions (Final Topical Report, September 30, 2012).
5. Modeling of CO_2 injection under in-situ conditions (Simulation Code/Module - March 31, 2012).
6. Modeling of CO_2 injection under in-situ conditions (Final Topical Report, September 30, 2012).

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Schedule – Deliverables (cont'd)

7. Advanced modeling of permeability changes during CO_2 sequestration (Final Topical Report, September 30, 2012).
8. Flow and storage modeling for shale sequestration (Final Topical Report, September 30, 2011).
9. Code validation using large-scale sequestration data sets (Final Topical Report, June 30, 2012).
10. Basin-oriented review of coal and shale storage potential – the Marcellus and Utica shales of the Appalachian Basin (Final Topical Report, March 31, 2012).
11. Basin-oriented review of coal and shale storage potential – the Fruitland Coal of the San Juan Basin (Final Topical Report, September 30, 2012).
12. Coal-Seq III – Forum 1 (January 2011)
13. Coal-Seq III – Forum 2 (June 2012)